A shared ” passengers & goods ” city logistics system

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Abstract:
Many strategic planning models have been developed to help decision making in city logistics. Such models do not take into account, or very few, the flow of passengers because the considered unit does not have the same nature (a person is active and a good is passive). However, it seems fundamental to gather the goods and the passengers in one model when their respective transports interact with each other. In this context, we suggest assessing a shared passengers & goods city logistics system where the spare capacity of public transport is used to distribute goods toward the city core. We model the problem as a vehicle routing problem with transfers and give a mathematical formulation. Then we propose an Adaptive Large Neighborhood Search (ALNS) to solve it. This approach is evaluated on data sets generated following a field study in the city of La Rochelle in France.

Keywords: *Transportation & distribution systems, shared passengers & goods city logistics systems, Vehicle Routing Problem (VRP), transhipment, Adaptive Large Neighborhood Search (ALNS).*

1 Introduction

Urban mobility is a complex system composed by passengers and goods transportation flows, strongly linked and in interaction (Goldman and Gorham, 2006; Malhéné and Breuil, 2010; Macario, 2011). Urban mobility significantly contributes to achieving socio-economic objectives of cities but at the same time it impacts on city living conditions in terms of congestion, emission and pollution[1].

Nowadays, cities are looking for instruments and policies to ensure an efficient and effective urban mobility for both passengers and goods. For this purpose, it is fundamental to manage urban mobility considering passengers and goods flows as a single logistics system (European Commission, 2007). This flows streamlining can be obtained through two fundamental concepts: consolidation and coordination. That means less vehicles travelling within the city and a better use of these vehicles. Different City Logistics Systems have been proposed and implemented in several cities, including: cooperative freight transport systems and advanced information systems. However, only few systems considered the passengers and goods flows together.

In this paper, we emphasize the idea of managing urban transportation flows making a joint use of transport resources between passengers and goods.

Starting from the statements that the total public transport capacity is currently under used[2] and the number and size of city operating freight vehicles are often oversized, we:

1. Define a two-tired model for a shared passengers & goods city logistics system. In the first system tier, goods are collected at a facility called the City Distribution Center (CDC). From CDC, goods are then loaded on buses, through the connection with the bus line. By mixing the two flows, passengers have priority. Goods, packed in roll containers, are loaded on the spare capacity of the bus. The suggested shared transportation model has to ensure the quality of service to passengers using public transport. In the second system tier, goods are unloaded at identified bus stops where they are transhipped to capillary logistics system using tricycles that deliver customers through near–zero emissions city freighters. This approach is much more flexible. It offers the advantage to adjust at any time the number of tricycles available at bus stops. Furthermore, delivery vehicles are synchronized with buses and ensure the transhipment operation, and avoid the installation of storage facilities at bus stops.
2. Suggest a model to dimension the number of tricycles allowing the satisfaction of the daily customer demand. We propose a heuristic method to solve the optimization problem formulated as a special case of two-echelon vehicle routing problem with transhipment.
3. Validate our model on data sets generated following a field study in the case study of La Rochelle city in France.

The paper is organized as follows. Section *2* presents a survey on the shared city logistics systems. Section 3

[1] www.civitas-initiative.org
[2] http://ec.europa.eu/transport/publications/statistics/statistics_en.htm

states the problem. Section 4 introduces the main formulation of the model. Section 5 describes the optimization approach. In section 6 we address the case study of La Rochelle city and we conclude in section 7.

2 Literature review

Various City Logistics Systems have been proposed and implemented in several cities, including: cooperative freight transport systems and advanced information systems. However, only few systems considered the passengers and goods flows together. Since passengers and goods do not have the same nature, a person is active and a good is passive, it seems more natural for public authorities, to manage each flow separately. Nevertheless, it is fundamental to adopt a different way to manage passengers and goods urban transportation considering all urban related flows as a single logistics system (European Commission, 2007).

2.1 Modelling approaches

Urban transport modelling is naturally separated in two parts: passengers on one hand and goods on the other hand.

Passengers urban transportation modelling began during the mid 1950s in the United States in order to help the decision-making process in transportation policy and more generally in land use strategy. Since then, urban transportation modelling has used single destination, separable purpose and daily trip based approach using four steps; trip generation, trip distribution, modal split and trip assignment. Variations of this four steps transportation system are used in most planning organizations for both long and short transportation planning (Southworth, 1995).

In the seventies, experts, researchers and engineers begin to focus on the urban goods distribution and especially on urban logistics by developing models to analyse the urban freight transit. Hutchinson (1974) developed the first urban goods transport models. These models estimate the trucks trips but are quite limited because just few types of goods are considered. Ogden (1992) proposed two categories of models: goods based models and vehicles based models. Anchored in the Hutchinson models and using urban passenger transport analogous approach, Ogden developed models aiming to analyse the generation of freight or vehicles trips among the category of goods. List and Turnquist (1994), He and Crainic (1998), Gorys and Hausmanis (1998), Harris and Liu (1998), Holguín-Veras and Thorson (2000) proposed also other approaches of modelling referred to gravitational, four-steps and input-output models. More recently, Munuzuri et al. (2004) proposed a methodology, based on entropy maximization, in order to build an Origin-Destination matrix for freight transport. Other kinds of models have lately merged. For example, Taniguchi et al. (1999) focused in finding the optimal size and location of Urban Distribution Centres. Thompson and Taniguchi (1999) tackle the city vehicle routing problem.

To the best of our knowledge, no modelling study related to the shared passengers & goods urban system was found in the literature. Oppenheim (1993) attempted to develop a combined approach considering passenger travel and goods movements with a spatial price equilibrium model but this kind of models look very data intensive. However, we found some projects exploring the pooling of resources. Theses experimental approaches are detailed in the next section.

2.3 Experimental approaches

In this section, we present a survey on cities experiments introducing shared urban transport solutions. We detected 14 cities that implemented 11 noteworthy shared solutions. These experiments are presented in table 1 and detailed in Trentini and Malhéné (2010b). Unfortunately sporadic information on implementation processes and outcomes is available. The more often cited difficulty to the setting up of shared solutions is to find a compromise accepted by all the stakeholders.

Three strategic directions emerge from this survey:

- Direction 1: improving the sharing of road space between private & public motorized road transport passengers flows and private motorized road transport goods flows;
- Direction 2: shifting passengers & goods flows from private motorized road transport to others urban transport modes;
- Direction 3: introducing distribution facilities in urban areas already devoted to passengers – i.e. car park areas, public transport stations, etc.

Table 1 establishes relation between the detected shared solutions and the strategic directions that they can achieve.

Existing Solutions	Dir.1	Dir. 2	Dir. 3
Multi - use lanes[3]	✓		
Night deliveries[2]	✓		
Shared Bus & lorry lanes[4]	✓		
Shared tramway , subway[5]		✓	
Shared Car sharing[3]		✓	
Shared delivery bays[6]			✓
Automatic goods lockers in car parks and underground stations[5]			✓
Delivery stations in car parks[5]			✓
Shared "passengers & goods" city logistics system	✓	✓	✓

Table 1: directions achieved by existing shared solutions and current positioning

The last row of the table shows that the suggested system aims at achieving all the three directions. At first, it should be able to improve the sharing of road, reducing the impact of utility vehicles, replaced by

[3] www.bestufs.net
[4] www.smartfreight.info
[5] www.apur.org
[6] www.sugarlogistics.eu

cargoticycles. Furthermore, using buses, our model should ensure shifting of goods from private motorized road transport. Finally, through the CDC, the system places distribution facilities in urban area, simplifying the supply chain process.

3 Problem statement

Most city logistics systems proposed and implemented include: cooperative freight transport systems and advanced information systems[7]. If punctual enhancements are perceived, caduceus results on the global urban mobility system are obtained, the respective transportation flows keeping interacting and slowing down (European Commission, 2007).

3.1 The conventional city logistics systems

As mentioned above, the stream of passengers and goods urban flows can be achieved through consolidation and coordination. Pertaining to goods, we can find city logistics systems operating one or more levels of consolidation, respectively named single–tiered, two–tiered or multi–tiered systems (Crainic et al., 2009). Multi–tiered systems are more complex and not contemplate in this paper.

Two–tiered systems are emerging for large cities. The first tier of the system consolidates loads at CDC into vehicles, which bring them to a smaller facility close to the city center. The second tier uses smaller vehicles, appropriate for city center activities, which deliver the goods to the final customers (Crainic et al., 2009). Single–tiered city logistics systems where consolidation activities take place at CDC are most frequent (Fig.1). Long–haul transportation vehicles of various modes dock at a CDC to unload their cargo. Loads are then sorted and consolidated into smaller vehicles for distribution (Crainic et al., 2009).

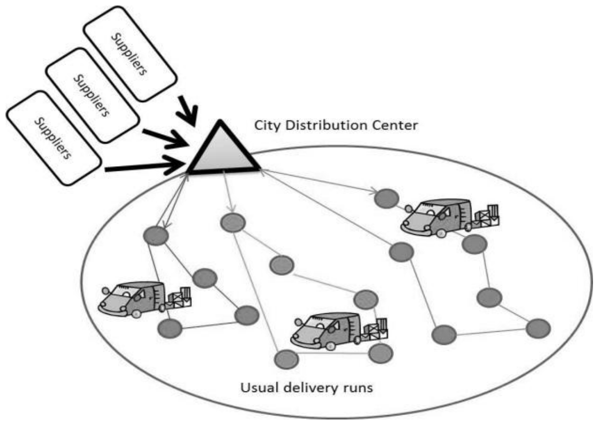

Figure 1: the conventional single-tiered system

Although the single–tiered urban logistics system is developed to reduce congestion and air pollution following theoretically efficient schemas, they are conditioned to usage rates that are not always reached (Dablanc, 2010; González-Feliu and Morana, 2010).

The first CDCs were private or semi-private initiatives, following economic and optimization interests. Later, environmental and social issues made public administrations to develop such systems for urban goods distribution (González-Feliu, 2008).

The literature about experiences of European CDCs shows that only few experiences are nowadays operating, and in many cases they need an important contribution of public authorities, both in terms of funding and organizational support (Taniguchi and van der Heijden, 2000; Taniguchi et al., 2001; Taniguchi and Thompson 2002; Monami et al., 2007).

Solving the single–tiered city logistics system amounts to solving a very classical problem in the field of operations research: the Vehicle Routing Problem with Time Windows (VRPTW). For more details, one can refer to Cordeau et al. (2002).

3.2 The shared city logistics system

We suggest a shared passengers & goods city logistics system where the spare capacity of a bus line is used to transport goods. All goods coming from the city outdoors are collected and stored in the CDC. From CDC, goods are loaded on buses, through the connection with the bus line, according to the buses spare capacity. Goods are then unloaded at identified bus stops where they are transhipped to capillary logistics systems that deliver them to customers through near – zero emissions city freighters.

Figure 2 represents the shared passengers & goods city logistics system.

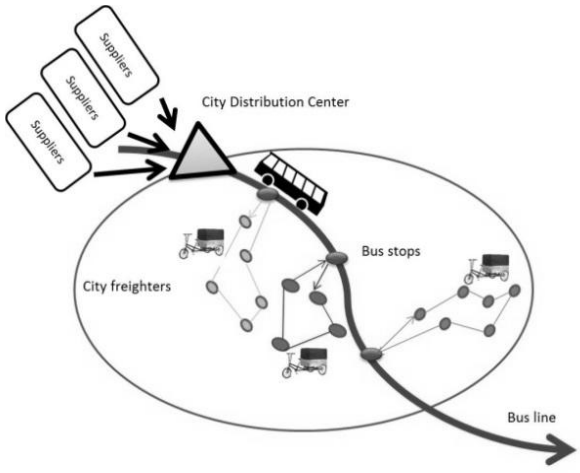

Figure 2: the shared passengers & goods city logistics system

The distribution system works on a daily basis. The goods to be delivered at day D arrive at the CDC at day D-1 until the middle of the night, and are dispatched by roll containers. Thus we can assume known customers demand and the distribution schedule has to be determined before the first bus leaves the CDC.

One strong assumption of the shared transportation model is that quality of service ensured to passengers

[7] www.moses-europe.org; www.mocuba.net; www.trailblazer.eu www.marketingpublictransport.eu; www.bestufs.net ; www.transports-marchandises-en-ville.org

using public transport remains unchanged whenever they share the buses with goods. The model assumes that the maximal number of roll containers that can be embarked by buses without deteriorating this quality of service is known. This number varies according to the buses utilization rate and is thus reduced at rush hours.

The transhipment operation consists in unloading the bus and loading the content of the roll container in a city freighter. Contrary to a cross-docking operation, the content of the roll remains unchanged. Moreover, we do not allow temporary storage of rolls at bus stops. This imposes a synchronization constraint between buses and city freighters.

We consider a general model where the city freighters may start and finish their working day at a known location called depot. In this paper, we assume that the depot is located at the CDC. This choice arises from the fact that we do not study the depot location.

For each city freighter, the day begins with an empty trip from the CDC to a bus stop. Then, one capillary route consists in picking one roll at a bus stop and delivering the goods to a set of customers. After each capillary route, the vehicle can go back to the same bus stop or be reassigned to another bus stop. The day finishes with an empty trip from the last customer of the last capillary route to the depot. The city freighters may be tricycles or electric cars.

The shared passengers & goods transport optimization problem shares some similarities with the two-echelon vehicle routing problems, or 2E-VRP (Perboli et al., 2011). In the classification of González-Feliu (2011), the problem belongs to the category of two-echelon problems with transhipment.

Considering the conventional transportation system where goods are delivered directly from the CDC with larger electrical vans, we aim to investigate the proposed two-echelon shared passengers & goods city logistic system. The model target is to evaluate the proposed system by considering the resources sizing and utilization.

4 Model formulation for the shared city logistics system

The following model is given to clearly define the optimization problem considered in this paper.

4.1 Problem settings and notations

The distribution process starts at a CDC, where the goods are packed in roll containers. Without loss of generality, we consider that containers have unitary capacity and that the demand of the customers is expressed as a percentage of this capacity (for larger demands, traditional delivery by truck will be preferred).

We denote C the set of customers. Each customer $i \in C$ has a known daily demand d_i that must be delivered in a time window $[e_i, l_i]$. One customer demand cannot be split in distinct rolls.

We consider a set B of bus trips from the CDC to the last bus stop considered in the problem. Each bus trip $b \in B$ has a fixed schedule and a known capacity for goods expressed as an integer number Q_b of roll containers.

The set of bus stops used as transhipment points is denoted S. A transhipment operation is possible whenever a bus $b \in B$ arrives at bus stop $s \in S$. Each bus trip $b \in B$ is a path that serves a set of transhipment nodes T_b, which contains one node per bus stop $s \in S$. The set of all transhipment nodes is denoted $T = \bigcup_{b \in B} T_b$. Each transhipment node $t \in T$ is associated with a capacity $\bar{Q}_t$ representing the maximal number of roll containers that can be unloaded at t.

We consider a set of identical city freighters with a capacity of exactly one roll container. We consider a set O of starting depots for the city freighters. In the same way, O' is a set of ending depots. In practice, O and O' can be identical. There can also be one common depot for the whole fleet of city freighters.

Denoting N the set of all nodes in the problem ($N = C \cup T \cup O \cup O'$), we define τ_{ij} as the travelling time to go from node $i \in N$ to node $j \in N$, and σ_i the service time at node $i \in N$. This service time corresponds to the unloading/loading operations at the transhipment node and the parking and service times at customer locations. Finally, M is an arbitrary large positive real value.

4.2 The mathematical model

The mathematical model considers the following variables. Decision variables $x_{i,j} = 1$ if a city freighter goes from node $i \in N$ to node $j \in N$, and 0 otherwise. Continuous variable c_i indicates the quantity of goods remaining in the vehicle after the service of customer $i \in C$. Continuous variable t_i denotes the time of service on node $i \in N$. Note that t_i is known for $i \in T$.

Following a classical approach in the literature in vehicle routing problems, we use a lexicographical minimization. The primary objective is to minimize the number of city freighters used. The secondary objective is to minimize the total time travelled by these vehicles.

Using the above introduced notation, the optimization problem can be formulated as follows:

$$(P) \qquad lex\ min \sum_{o \epsilon O} \sum_{i \epsilon N \setminus O'} x_{o,i} \ , \sum_{i,j \epsilon N} \tau_{i,j} x_{i,j}$$

s.t.

$$\sum_{i \in N} x_{o,i} = 1 \qquad \forall o \in O \qquad \text{(c1)}$$

$$\sum_{i \in N} x_{i,o'} = 1 \qquad \forall o' \in O' \qquad \text{(c2)}$$

$$\sum_{i \in N \setminus \{O \cup O'\}} x_{i,c} = 1 \qquad \forall c \in C \qquad \text{(c3)}$$

$$\sum_{j\in N} x_{i,j} = \sum_{j\in N} x_{j,i} \qquad \forall i \in N\backslash\{O \cup O'\} \qquad (c4)$$
$$c_i \le c_j - d_i + M(1 - x_{j,i}) \qquad \forall i \in C, j \in N \qquad (c5)$$
$$t_i \ge t_j + \sigma_j + \tau_{j,i} - M(1 - x_{j,i}) \qquad \forall i,j \in N \qquad (c6)$$
$$\sum_{i\in N} x_{i,t} \le \bar{Q}_t \qquad \forall t \in T \qquad (c7)$$
$$\sum_{t\in T_b} \sum_{i\in N} x_{i,t} \le Q_b \qquad \forall b \in B \qquad (c8)$$
$$x_{i,j} \in \{0,1\} \qquad \forall i,j \in N \qquad (c9)$$
$$c_i \in [0,1] \qquad \forall i \in N \qquad (c10)$$
$$t_i \in [e_i, l_i] \qquad \forall i \in N \qquad (c11)$$

The objective function minimizes first the number of vehicles used then the distance covered. Constraints (c1) guarantee that for each vehicle exits a starting depot. Constraints (c2) guarantee that each vehicle returns to an ending depot. Constraints (c3) state that each client is serviced exactly once. Constraints (c4) state that if a vehicle enters a node, it should also leave the node. Constraints (c5) establish the quantity of goods remaining in the roll containers after visiting each customer. Note that city freighters can be replenished at transhipment nodes because flow conservation is not required at these nodes. Constraints (c6) concern the time of service on the nodes. Synchronization between buses and city freighters is ensured because t_j is fixed for $j \in T$. Constraints (c7) guarantee that the capacity of the bus stops is respected. Constraints (c8) state that the capacity of the buses is respected. Constraints (c9)-(c11) define the domain of the decision variables.

The problem (P) is a routing problem with two echelons, with the following strong characteristics: (i) all routes between the CDC and the bus stops are imposed and follow the bus line itinerary, (ii) the load of the buses is an integer number of rolls, (iii) no material can be stored at the transhipment points.

5 Adaptive Large Neighborhood Search (ALNS)

In this section we describe the Adaptive Large Neighbourhood Search (ALNS) algorithm used to solve (P).

5.1 Main principale of ALNS

The ALNS is the adaptive extension of the Large Neighborhood Search (LNS) metaheuristic. It has been described by Pisinger and Ropke (2007) in the context of vehicle routing problems and has proved its efficiency for solving a large variety of problems: the Pickup and Delivery Problem with Time Windows (PDPTW) (Ropke and Pisinger, 2006), the two-echelon vehicle routing problem (Hemmelmayr et al., 2011), a multicriteria Dial-a-Ride Problem (DARP) (Lehuédé et al. 2011).

A close problem to (P) is the Pickup and Delivery Problem with Transfers (PDPT). The PDPT considers each demand as a transportation request between a pickup point and a delivery point with the possibility of transferring the goods at some transfer points. Cortés et al. (2010) propose an extensive mathematical formulation of the PDPT and an exact method capable of solving small instances. Masson et al (2012) propose an ALNS for the PDPT and solve instances with up to 193 pickups and 5 delivery points, or 84 pickups and 33 delivery points. In the case of a shared urban transport system, the number of distinct delivery points is likely to reach a few hundred points. Fortunately, there are several simplifications compared with the general PDPT: (i) the CDC is the only pickup point, (ii) the route and the timetable of buses is known (iii) we do not consider delivering some customers directly from the buses. In other words, the decision of transferring goods or not does not have to be taken. Hence, the algorithm used to solve (P) is an adaptation of the ALNS described in Masson et al (2012).

The general functioning of the ALNS is depicted by Algorithm 1.

```
1 Build an Initial Solution: S0
2 Initialize the best solution: S* ← S0
3 Current solution: S ← S0
4 While the termination criterion is not satisfied
5   Select Destroy and Repair methods
6   S' ← S
7   S ← Destroy(S)
8   S ← Repair(S)
9   Update score of Destroy and Repair methods
10  If S improves S* then S* ← S and S' ← S
11  Else if AcceptanceCriterion(S',S) then S' ← S
12  S ← S'
13 EndWhile
14 Return S*
```

Algorithm 1: ALNS

At each iteration, the current solution is modified by using a *destroy* (line 7) and a *repair* (line 8) method. A destroy method destroys a percentage α% of the current solution while a repair method rebuilds the destroyed solution. The repair method reinserts customers in the new solution until a feasible solution is reached or no more feasible insertion can be found. In the latter case, the remaining demands are placed in a *request bank*. The destroy and repair methods are selected among a list of candidate methods, using a roulette wheel selection procedure (line 5). The probability of being selected depends of the past efficiency of each method.

Line 9 introduces the *adaptive aspect* of the ALNS: the probability of choosing each destroy and repair method is updated every hundred iterations. The scores favour destroy and repair methods that have been able to exhibit new best solutions, solutions improving the current one or solutions not yet encountered. In this way, the adaptive aspect ensures both intensification and diversification of the metaheuristic.

Line 11 introduces the *acceptance criterion* borrowed to simulated annealing: if the result of the destroy+repair method improves the current solution, the new solution is always accepted. Otherwise, the decision to accept a new solution is taken according to a Simulated Annealing criterion. The probability of accepting a degradation of the current solution is controlled by some decreasing parameter called the temperature. We set the starting temperature in such a way that a solution 5% worse than the initial solution has a 50% chance of being accepted.

Next subsections detail the destroy and repair methods used in the implementation of the ALNS. These methods are detailed in Pisinger and Ropke (2007) or Masson et al (2012).

5.2 Destroy methods

At each iteration, a given number of customer demands are removed from the routes in which they are serviced. This removal is performed by a method which selects a percentage α of the requests, chosen randomly in the interval [10%, 20%]. We used five destroy methods:

1. The ***Random Removal*** method randomly selects α % of the customers to be removed from the solution.
2. The ***Worst removal*** method first computes the cost saving produced by the removal of each customer. α% of the customers are then selected randomly, with a probability of being selected increasing with the savings.
3. The ***Related removal*** aims at simultaneously removing customers with high relatedness. The relatedness measure of two customers depends on the distance between their geographical location, the difference between their time of service and the difference in load.
4. The ***History removal*** aims at removing the customers that seem poorly placed in the current solution with regard to the best known solutions. At each iteration a score is calculated for each customer, based on a comparison with the 50 best known solutions Nodes with lowest scores are removed.
5. The ***Transfer point removal*** method consists in rerouting all demands from one transhipment point to another one. Demands that are served from given transfer point are removed simultaneously to give them a chance to be rerouted through another transfer point.
6. ***Cluster removal***: this method aims to remove simultaneously a given number of customers that can be efficiently routed through a common transfer point. Indeed a set of customers located in the same area will probably benefit from using the same transhipment node.

5.3 Repair methods

We adapted the classical insertion methods based on best insertion and regret principles in order to handle the transhipment at bus stops:

1. The ***Best insertion*** method computes the best insertion cost for each destroyed customer. The customer with the lowest insertion cost is inserted at its best position. The method stops when all customers are routed or none can be inserted.
2. The ***Regret-k insertion*** method is based on the classical notion of regret used for the Vehicle Routing Problems. For each undelivered customer, the k best possible insertion costs are computed for each route. The regrets are defined as the differences between the best insertion and the j^{th} best insertion cost is computed for j=2,…,k. The method iteratively inserts the customer with the maximal sum of regrets.

6 A case study in La Rochelle

6.1 Presentation of the case study

The urban area of La Rochelle has a population of 127000 inhabitants (ranked 55 in France). The area of interest is the inner center, represented in Figure 3. It represents the most attractive area, with 10827 inhabitants and almost 2000 economic activities. The inner zone is crossed by a bus line named Illico.

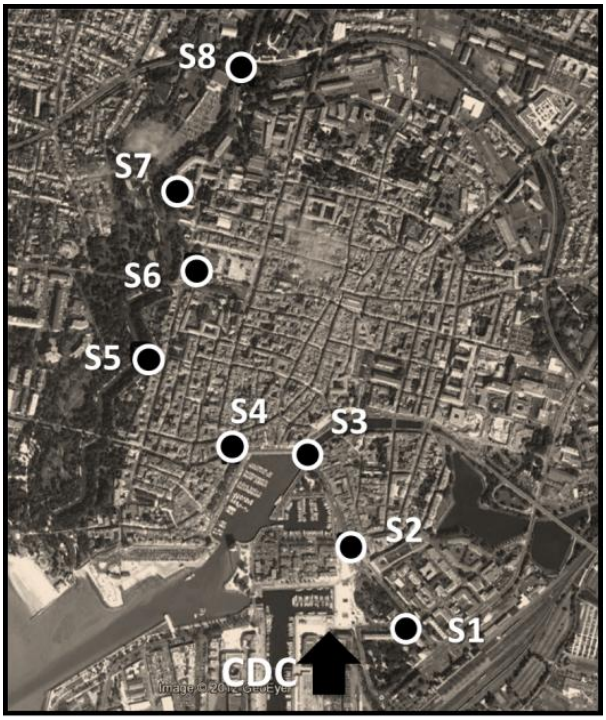

Figure 3: the inner center, the CDC and the bus line Illico

For practical implementation the goods are loaded into buses at the CDC and transhipped at one of the eight bus stops denoted S1 to S8.

To define an appropriate sizing of the delivered freight flows volumes, we suggested a methodology, based on the existing literature (e.g. Danielis et al. 2010; Allen and Browne 2010). The methodology is structured on three phases.

In the first phase, it has been necessary to collect data to understand the economical characteristics of the considered zone (the density and the surface of production, commercial, handicraft activities, etc.). The second phase allowed identifying seven types of businesses of particular relevance in the urban context. They are grocers, public offices, hotels, tertiary offices/services, bars, restaurants, clothing stores. In the third phase a survey was carried on the delivery assortment type, the product value, the product volume and the delivery frequency. A questionnaire allowed us to provide this information covering the 60% of the total number of the considered zone establishments, or 1662 customers.

This sample, ranked by categories with a known profile of demand and time windows for delivery has been used for the case study tests. The rate of occupancy in each bus of the line Illico at any bus stop has also been collected. This resulted in an estimation of the maximal number of rolls in each bus.

We generated five subsets of customers in the inner center. The subsets contain between 105 and 303 potential customers, representing all categories of shops or administrations. We associate each customer with a time window of 1, 2 or 4 hours and a time of service of 5 minutes.

From each subset of customers we created three scenarios with increasing levels of demand (noted a, b and c respectively). This yields 15 instances described in Table 2. Column 1 represents the name of the instance, built from the number of customers and the letter a, b or c. Next columns describe the main characteristics of the demand, expressed as a percentage of a full roll: minimal demand (column 2) among the customers, average demand (column 3), maximal demand among the customers (column 4) and standard deviation (column 5).

	Customers' demand (*in % of roll*)			
Instances	*Min*	*Avg*	*Max*	*StdDev*
105-a	8	25.8	77	11.2
105-b	10	33.4	72	12.6
105-c	15	42.1	100	15.3
150-a	5	24.2	61	10.0
150-b	12	34.5	89	14.4
150-c	12	41.7	91	15.1
196-a	5	26.0	80	12.1
196-b	9	35.1	88	14.7
196-c	16	42.9	91	15.0
246-a	5	26.2	80	12.5
246-b	10	33.5	88	13.1
246-c	15	42.7	100	15.8
303-a	5	25.4	74	12.7
303-b	5	33.3	78	13.0
303-c	12	41.8	100	16.1

Table 2: description of the instances

The single–tiered system assumes the use of electric trucks with a capacity of 2 tons. The shared passengers & goods system assumes the use of electric tricycles with a capacity of 100 kg.

6.2 Numerical experiments

Table 3 presents the numerical results obtained after one hour of calculation for each scenario, on a desktop computer with an i3-530 processor, running Ubuntu 10.04. Column 2 gives the number of trucks in the single–tiered system and column 3 the corresponding distance travelled. Column 4 shows the number of tricycles required in the shared system and column 5 the distance travelled by the tricycles.

Columns 2 and 3 of Table 3 show that the fleet of electric trucks is quite stable with respect to increase of customers' demand. On the contrary, the number of tricycles increases quite linearly.

	Single–tiered system		Shared passengers & goods system	
Instance	*trucks*	*Km*	*tricycles*	*km*
105-a	2	47,5	2	41,4
105-b	2	54,7	2	48,2
105-c	2	52,1	3	51,8
150-a	3	70,5	3	56,5
150-b	3	66,1	3	70,4
150-c	3	66,8	4	76,1
196-a	3	78,9	4	74,7
196-b	3	91,2	4	87,6
196-c	3	103,0	4	104,8
246-a	3	105,7	4	97,1
246-b	3	110,9	5	106,6
246-c	3	118,4	5	130,5
303-a	4	105,9	5	118,7
303-b	4	119,6	5	143,8
303-c	4	126,4	6	162,6

Table 3: number of vehicle and distance travelled

When the customers' demand increase, the distance travelled by tricycles exceeds the distance in the single–tiered system. These results can be explained by the vehicles' load and capacity. The trucks are generally not fully utilized. On the other hand, due to their small capacity, tricycles have to perform several routes from a transhipment point to a restricted set of customers. When the customers' demand increases, the average number of customers by route decreases, so that tricycles perform more routes and more empty trips back to the transhipment point.

This idea is confirmed in Table 4. The values in column 2 express the average number of full loads transported by trucks. It is calculated as the ratio between the total load carried and the global available capacity (number of trucks used × 2000kg). Column 3 expresses the same idea with the tricycles. The values in columns 4 and 5 represent the number of rolls containers needed and their average load (in % of their capacity).

It is noticeable that the use of vehicles increases when the number of customers increases. Indeed, higher customer density enables the algorithm to build shorter routes. The number of rolls is calculated with the assumptions that the whole set of customers demands is prepared a priori at the CDC. Allowing the preparation of roll containers in parallel with the distribution would enable to re-use empty rolls returning back from transhipment points, and thus to decrease the initial investment in roll containers. This reverse logistics aspect is not taken into account in the present study. On average the roll container are loaded at 87% of their capacity. Note that we did not consider 3D packing constraints in the loading of the roll containers.

	single–tiered system	Shared passengers & goods system		
Instance	*use of trucks*	*use of tricycles*	*rolls*	*Average load*
105-a	0,68	13,5	23	93%
105-b	0,90	18,0	31	91%
105-c	1,13	15,0	40	90%
150-a	0,63	12,7	27	82%
150-b	0,84	16,9	45	94%
150-c	1,05	15,8	55	89%
196-a	0,84	12,6	40	84%
196-b	1,12	16,8	54	87%
196-c	1,40	17,5	71	90%
246-a	1,05	13,7	47	82%
246-b	1,40	16,8	68	84%
246-c	1,75	21,0	90	88%
303-a	0,98	15,6	62	84%
303-b	1,30	18,0	81	80%
303-c	1,63	21,7	111	86%

Table 4: Utilization of the vehicles

Table 5 focuses on the utilization of bus stops. Columns 2 to 7 represent the number of rolls loaded by tricycles at the bus stops S1 to S6.

Instance	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
105-a	1	2	12	8	1	7
105-b	2	3	16	11	3	8
105-c	4	3	20	12	4	8
150-a	3	4	14	10	5	9
150-b	3	5	23	15	6	10
150-c	4	5	26	19	7	12
196-a	3	4	20	13	4	15
196-b	4	5	31	16	7	14
196-c	3	6	43	21	6	17
246-a	4	6	26	15	8	15
246-b	4	7	37	21	8	17
246-c	6	9	53	24	10	21
303-a	4	8	34	18	7	16
303-b	4	9	46	22	13	20
303-c	6	11	61	33	10	26

Table 5: utilization of the bus stops

There is a huge difference in the utilization of the bus stops. Stops 3 and 4 represent 60% of the total flow. Whereas the total number of bus stops considered for the numerical experiments was 8, the outgoing flow from the CDC and bus stops 7 and 8 is negligible. This is explained by the La Rochelle urban structure, with businesses condensed in the city core.

These results raise the more general question of the optimal location of transhipment points: is it possible to select only a subset of bus stop for the transhipment of the rolls, with limited impact on the quality of service.

An important factor for the quality of service to the customers is the width of time windows. We explored the case where the width of the time windows is reduced to 1 hour for every customer. The results are presented in Table 6. Columns 2 and 4 express the number of trucks and tricycles required in each transportation system. Columns 3 and 5 represent the utilization rate of each vehicle. These values can be compared with the ones in Table 4.

The reduction of time windows improves the quality of service but at the price of a huge increase of the number of vehicles (trucks or tricycles) and a dramatic decrease of their utilization. This illustrates the difficulty in finding a trade-off between the logistic efficiency, the environmental concerns and the quality of goods delivery service to customers.

	Single–tiered system		Shared passengers & goods system	
Instance	*trucks*	*Use of trucks*	*tricycles*	*Use of tricycles*
105-a	4	0,34	4	5,6
105-b	4	0,45	5	7,2
105-c	4	0,56	5	8,4
150-a	5	0,38	6	5,6
150-b	5	0,51	7	7,2
150-c	5	0,63	8	7,9
196-a	7	0,36	8	6,3
196-b	7	0,48	9	7,4
196-c	7	0,6	13	6,4
246-a	8	0,39	10	6,3
246-b	8	0,53	11	7,4
246-c	8	0,66	16	6,3
303-a	9	0,43	12	6,5
303-b	9	0,58	15	6,8
303-c	9	0,72	23	5,7

Table 6: Results with time windows of 1 hour.

7 Conclusion

In this paper, we suggested a new city logistics system in which the public transport spare capacity is used to distribute goods toward the city core. We propose a mathematical model to assess the feasibility of such a shared organization. Based on the case study of the city of La Rochelle in France, we propose an optimization approach that considers the problem as a Vehicle Routing Problem With Transfers. The numerical results confirm the intuitive idea that the efficiency of a shared passengers & goods transportation system is particularly adapted for delivering small parcels to a large number of customers in a restricted geographical area.

This paper is a first optimization approach to assess shared urban transport. A deeper analysis, including the financial, organizational and legal barriers to the shared system, needs to be developed in order to determine the real efficiency of the proposed system.

As far as the modelling is concerned, we ignored several fixed costs associated with the initial investments: purchase of vehicle and rolls, conversion of bus stops to transhipment areas. An exhaustive study would also integrate variable costs (salary of drivers and staff travelling with rolls inside buses) and survey the actual travelling and service times. Finally, we only considered the weight of the parcels and relaxed 3D-packing constraints.

The model can be up-scaled, considering several bus lines, several CDCs and the possibility to mix the fleet of trucks and city freighters. We made the assumption that almost every bus stop in the inner city was used as a transfer point. This makes sense from a mathematical point of view but raises difficulties in the practical implementation of the system. Selecting a subset of efficient transhipment point would result in a slightly sub-optimal but much clearer network.

Another important aspect concerns the reverse logistics. Empty rolls containers are not available until they are returned to the CDC and filled again. Integrating the management of empty rolls in the model raises new constraints in the distribution planning. Finally, another aspect to investigate pertains to the technological solutions to improve loading/unloading operations at the transhipment points.

A mix of policies should be applied to improve urban mobility. A detailed, city-specific cost-benefit analysis encompassing private and social costs and benefits in the short and long run is also needed. In particular, the CO2 emissions, noise and traffic congestion are parameters with high political impact.

The final objective of the research is to drive public transport authorities to negotiate in order to minimize the transportation and environmental costs in urban transports. Political decisions, technical coherence and involvement of actors are the foundations of urban mobility projects.

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